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ABSTRACT Monitoring vegetation with a modified Robel pole on the Fort Pierre National Grassland was evaluated for combined shallow clay and loamy overflow ecological sites (dominated by warm season grasses), and for clayey ecological sites (dominated by cool season grasses). My objectives were to 1) develop a relationship between visual obstruction readings (VOR) and standing herbage, 2) provide guidelines for vegetation monitoring, and 3) evaluate vegetation monitoring during the growing season for clayey ecological sites. The relationship between visual obstruction readings and standing herbage was linear and regression coefficients were highly significant ($P < 0.001$) for both ecological types. Cluster analyses for shallow clay and loamy overflow ecological sites grouped the VOR and standing herbage ($kg \bullet ha^{-1}$) into 4 resource categories. Monitoring with 4 transects will provide adequate information to estimate standing herbage within 259 ha (1 section). Three resource categories (VOR + herbage) for clayey ecological sites were defined by cluster analyses. Monitoring with 4 transects was determined to provide reliable estimates of standing herbage. July validation of vegetation with the developed clayey ecological site model will provide reliable monitoring of standing herbage from July through November for this ecological site.

KEY WORDS grazing, livestock, management, Robel pole, structure, vegetation, wildlife

Monitoring standing herbage and visual obstruction readings (VOR) on grasslands with improved and efficient scientific methodologies are essential for management of livestock grazing, wildlife habitat and for plant and animal diversity. Development of resource guidelines for monitoring residual standing herbage from VOR estimates is relevant for today's resource managers (Bement 1969, Holechek et al. 1989, Heady and Child 1994, Mergen et al. 2001, Molinar et al. 2001). Most techniques for estimating weight of vegetation are difficult to apply, costly, and time-consuming (Pechanec and Pickford 1937, Wilm et al. 1944, NAS-NRC 1962, Bonham 1989). For these reasons, visual or ocular estimates are commonly used for monitoring grassland vegetation and utilization by herbivores. While efficient, these techniques have drawbacks. Visual or ocular estimates are variable among observers (Schultz et al. 1961, Kershaw 1973, Block et al. 1987, Irving et al. 1995). Moreover, many users omit a training phase where they compare estimates to clipped vegetation measurements.

The Robel pole has received considerable attention in the literature over the past 40 years (Robel et al. 1970, Volesky et al. 1999, Vermeire and Gillen 2001, Uresk and Benzon 2007, Uresk et al. 2010). The modified Robel pole with 2.54-cm grey-and-white bands is an improved method for monitoring standing herbage and structure of grasslands (Benkobi et al. 2000). Once the relationship between visual obstruction readings (VOR) and standing herbage (live and dead) has been developed, the modified pole is quick, simple, accurate, precise, and cost-effective.

Establishing VOR guidelines to leave an adequate amount of residual herbage at the end of a grazing season is important for ecological sites to provide early spring growth and prevent water erosion at the start of the next season. Adequate residual herbage results in cooler soil for a longer period of plant growth, more soil water storage with less runoff and sediment yield, and later maturation with greater plant production overall when compared to over use by herbivores (Beetle et al. 1961, Molinar et al. 2001). The objectives of this study were to 1) develop the relationship between VOR and standing herbage, 2) provide guidelines for monitoring, and 3) evaluate monitoring effectiveness for clayey ecological sites.

STUDY AREA

My study area was located on the Fort Pierre National Grassland (FPNG) in central South Dakota. These grasslands included approximately 46,964 ha (116,000 acres) of federal lands with private lands intermixed and characterized by nearly flat to rolling plains. Elevation ranged from 427 m to 701 m above sea level. Soils were primarily clayey and shallow clay. Shallow clay and loamy overflow ecological sites were dominated by warm season grasses, particularly big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* [Michx] Nash var. *scoparium*), side-oats grama (*Bouteloua curtipendula* [Michx] Torr.), and blue grama (*B. gracilis* [Willd. *ex* Kunth] Lag. *ex* Griffiths; USDA-NRCS 2008*a*, 2009). The clayey ecological sites were dominated by cool season grasses including green needlegrass (*Nassella viridula* [Trin.] Barkworth) and western wheatgrass (*Pascopyrum smithii* [Rydb.] A. Löve; USDA-NRCS 2008*b*). Plant nomenclature followed USDA-NRCS (2011). Precipitation ranged from 16.2 to 60.5 cm with an annual

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average of 42.1 cm, most occurring in spring (High Plains Regional Climate Center 2011). Average monthly temperatures ranged from 1.4 to 16.8° C.

METHODS

I sampled shallow clay and loamy overflow ecological sites and clayey ecological sites in October–November 1996 after first hard frost; all procedures and methods follow Benkobi et al. (2000). I painted a modified 2.54-cm diameter Robel pole with alternating white-and-grey 2.54-cm bands. I numbered bands beginning with 1 at the bottom. I determined VOR at a distance 4 m with the reader's eye at a height of 1 m, and recorded the lowest visible band. Transects were 200 m long and I recorded VOR at 20 stations spaced at 10-m intervals. I recorded readings at each station in each of the four cardinal directions. At four stations (50, 100, 150, and 200 m along transects), I placed the pole in the center of a 0.25-m^2 hoop, recorded VOR, and clipped all vegetation within the hoop at ground level. I oven dried clipped vegetation at 60° C for 48 hrs. I weighed dried vegetation to the nearest 0.1 g and expressed standing herbage in kg•ha^{-1}. (ShelLab Oven, Scale is an A & D Electronic Balance, FX-6000, Japan)

I used a stratified random sampling design to collect all transects throughout the study area for combined shallow clay and loamy overflow ecological sites (dominated by warm season grasses), and for clayey ecological sites (dominated by cool season grass) based on the amount of vegetation from three strata: short, mid and tall (Cochran 1977, Thompson et al. 1998, Levy and Lemeshow 1999). I randomly located transects within each stratum throughout the grassland for each of the ecological sites. I collected additional validation data for clayey ecological sites dominated by cool season grasses near peak growth from high to low (grazed) VOR in July 2009 to determine if monitoring vegetation throughout the grazing season would be feasible, since model data were collected in the fall.

I applied linear regression (SPSS 2003) to quantify the relationships between VORs and standing herbage; validation data were not included in these analyses. I averaged data for all VORs including validation data and standing herbage over transects. I developed regression models for combined shallow clay and loamy overflow ecological sites, and for the clayey ecological sites. I used a non-hierarchical cluster analysis (ISODATA) to develop resource categories (Ball and Hall 1967, del Morel 1975) for management guidelines. I standardized VORs and kg•ha^{-1} to give equal weight for analyses (individual data subtracted from the sample mean/standard deviation). I estimated sample sizes for future transects specifying the relative error to be 20% of the mean with 80% confidence based on the regression variance (Cochran 1977). I evaluated validation data for clayey ecological sites collected during peak standing herbage using 95% prediction intervals and screened data for outliers greater than 3 standard deviations for prediction from the predicted values.

RESULTS

Shallow Clay and Loamy overflow ecological sites

Clipped herbage for 209 transects yielded estimates of 704 to 8,731 kg•ha^{-1} on grazed and ungrazed pastures with a mean of 3,449 kg•ha^{-1}. Visual obstruction readings ranged from 1 to 12 bands with a mean of 4.7. The relationship between VOR and clipped standing herbage was linear with a coefficient of determination of 0.79 (Fig.1). The regression model, intercept, slope and coefficient of determination were significant ($P \leq 0.001$). I examined residuals by normal probability plots that showed they were normally distributed. Slope of the regression was 555.5 kg•ha^{-1} per band with an intercept of 863.4 kg•ha^{-1}; standard error of the estimate was 754 kg• ha^{-1}.

Cluster analyses with VOR and clipped herbage resulted in four distinct minimum variance categories (Table 1). Categories were defined as short (1.0–3.0 bands), short intermediate (3.1–5.5 bands), tall intermediate (5.6–8.4 bands), and tall (8.5–12.0+ bands). Standing herbage weights (kg•ha^{-1}) derived from the regression model ranged from 1,419–2,530, 2,585–3,919, 3,974–5,530 and 5,585–7,529 among the four categories, respectively. Band 5 (3,641 kg•ha^{-1}) corresponded to approximately 40% utilization based on the average standing herbage potential of 6,196 kg•ha^{-1} (Table 1).

Clayey Ecological Sites

Clipped standing herbage on 182 transects ranged from 336 to 5,745 kg•ha^{-1} with a mean of 2,338 kg•ha^{-1}. Visual obstruction readings varied from 1.0 to 10.5 bands with a mean of 3.5. The regression model was linear with a coefficient of determination of 0.82 (Fig. 2). Intercept, slope and coefficient of determination were significant at $P \leq 0.001$. Residuals on probability plots were normally distributed. Slope of the regression was 524.8 kg•ha^{-1} per band. The intercept was 517.6 kg•ha^{-1} and the standard error of the estimate was 577 kg•ha^{-1}.

I defined three categories with minimum variances by cluster analyses, VOR and clipped herbage (Table 2). These VOR categories were short (1.0–2.7 bands), intermediate (2.8–5.5 bands) and tall (5.6–10.5+ bands). Standing herbage (kg•ha^{-1}) categories resulting from the regression model were 1,042–1,934 (short), 1,987–3,404 (intermediate), and 3,456–6,027 (tall). Mean of the tall category was 4,348 kg•ha^{-1} with an average VOR of 7.3 bands (Table 2). Approximately 40% utilization of mean potential herbage (Table 2) equated to band 4 or 2,609 kg•ha^{-1}. All validation transects collected in 2009 except one out of nine fell within the 95% prediction intervals

(Table 3). However, one transect was an outlier of greater than 3 standard deviations.

DISCUSSION

A comparison of Robel pole models based on regression slopes (kg•ha^{-1}*band [2.54 cm]) with the model developed by Benkobi et al. (2000) on a sandy ecological site in the Sand Hills of Nebraska showed differences in regression slopes between different vegetation types and regions based on other studies. In this study, the regression slope for the clayey ecological sites was 15% lower than the slope reported by Benkobi et al. (2000), while the combined shallow clay and loamy overflow ecological sites yielded a slope 10% lower. Compared to Benkobi et al. (2000), Robel et al. (1970) in Kansas showed a 53% lower regression slope. Other studies reported by Uresk et al. (2009*a*) in the northern Black Hills, SD and Uresk et al. (2010) in the Big Horn Mountains, WY, showed 76% and 45% lower regression slopes, respectively, compared to Benkobi et al. (2000). No single model would apply across regions and ecological site types, thus new regression models relating standing herbage with VOR are required for each ecological site and region.

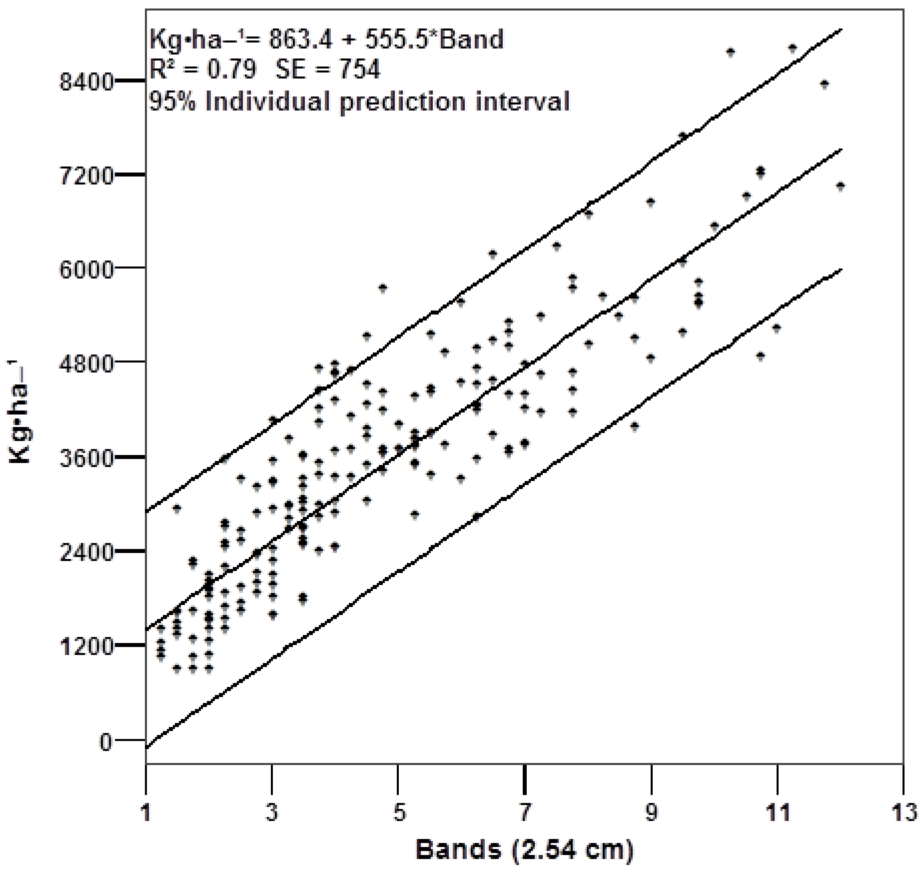

Figure 1. Regression relationship between Visual Obstruction Readings (VOR) bands and standing herbage (kg•ha^{-1}) for shallow clay and loamy overflow ecological sites dominated by warm season grasses with 95% prediction intervals for individual transects in central South Dakota, 1996.

Guidelines for monitoring residual standing herbage on shallow clay and loamy overflow ecological sites and on clayey ecological sites based on VOR estimates are relevant to today's resource managers for maintaining healthy rangelands. When using the residual based method calibrated for VOR with clipped standing herbage, a predetermined amount (fixed Robel pole band) can be maintained at the end of the grazing season yearly. Managers can monitor the amount of residual standing herbage with a high degree of accuracy (Bonham 1989, Heady and Child 1994, Benkobi et al. 2000, Uresk and Juntti 2008, Uresk et al. 2010). Thus, monitoring residual herbage was more precise and efficient than measuring utilization. To aid in the transition between the two methods, my results suggested that 40% utilization corresponded to band 5 for ecological sites dominated by warm season grasses and band 4 for ecological sites dominated by cool season grasses. A 40% utilization was considered the long term standard for maintaining grasslands in a healthy condition (Holechek et al. 1989, Heady and Child 1994). The estimated number of transects required for monitoring to achieve a relative error of 20% of the mean with 80% confidence to estimate standing herbage was 4 transects for key areas of 259 ha (1 section) or less (Benkobi et al. 2000).

Table 1. Shallow clay and loamy overflow ecological sites dominated by warm season grass resource categories defined by cluster analysis for short, short intermediate, tall intermediate and tall standing herbage. Band (2.54 cm) represented visual obstruction reading (VOR).

Category	Band/Kg•ha^{-1}	Min	Mean	Max
Short (*n* = 64)[a]	Band	1.0	2.1	3.0
	Kg•ha^{-1} [b]	1,419	2,030	2,530
Short intermediate (*n* = 75)	Band	3.1	4.0	5.5
	Kg•ha^{-1}	2,585	3,085	3,919
Tall intermediate (*n* = 43)	Band	5.6	6.3	8.4
	Kg•ha^{-1}	3,974	4,363	5,530
Tall (*n* = 27)	Band	8.5	9.6	12.0+
	Kg•ha^{-1}	5,585	6,196	7,529

[a] Number of transects; [b] Kg•ha^{-1} based on VOR band-weight equation (shallow clay and loamy overflow soils).

Table 2. Clayey ecological sites dominated by cool season grass resource categories defined by cluster analysis for short, intermediate, and tall standing herbage. Band (2.54 cm) represented visual obstruction reading (VOR).

Category	Band/Kg•ha^{-1}	Min	Mean	Max
Short (*n* = 95)[a]	Band	1.0	1.8	2.7
	Kg•ha^{-1} [b]	1,042	1,462	1,934
Intermediate (*n* = 49)	Band	2.8	3.7	5.5
	Kg•ha^{-1}	1,987	2,459	3,404
Tall (*n* = 38)	Band	5.6	7.3	10.5+
	Kg•ha^{-1}	3,456	4,348	6,027

[a] Number of transects; [b] Kg•ha^{-1} based on VOR band-weight equation (Clayey soil).

Resource categories developed for ecological sites dominated with warm or cool season grasses provided useful guidelines for management of livestock, wildlife habitat and diversity of plants and animals to meet other management objectives. Managers can relate these categories to grazing rates described as none to light, moderate and heavy. These guidelines provided managers a direction to maintain current or develop new objectives to achieve the desired grassland condition. For example, in consideration of grouse nesting habitat, it was prudent to manage at approximately band 4 (>8.6 cm of residual herbage; Prose et al. 2002). However, to maintain black-tailed prairie dogs colonies with limited or no expansion, band 2.5 was recommended based on the midpoint VOR regardless of plant species composition (Severson and Plumb 1998). Visual obstruction readings of less than band 2.5 would establish a height density conducive for prairie dog expansion. Approximately 10–15% of the landscape on these grasslands was recommended to be maintained in short and tall categories with the remainder of the area in the intermediate categories (Kershaw 1973, Mueller-Dombois and Ellenberg 1974, Steel and Torrie 1980). This would provide a mixture of habitats on the landscape to maintain plant and animal diversity (Uresk 1990, Benkobi et al. 2007, Fritcher et al. 2004, Rumble and Gobeille 1998).

A transect integrates an area of standing herbage over 1600 m^2, 8 × 200 m in length (Uresk et al. 2010). When the objective is to manage for an established VOR and it warrants removal of livestock, a 1-sided t-test (α = 0.05) using the variance of the 4 transects collected on a 259 ha area is appropriate for testing differences from established bands of 4 and 5 in this study (Steel and Torrie 1980, Uresk and Juntti 2008 Uresk et al. 2010). Validation data collected in July showed that the model for clayey ecological sites dominated with cool season grasses can be used to monitor standing herbage and livestock grazing from near peak standing herbage to the end of the grazing season at first hard frost with four transects.

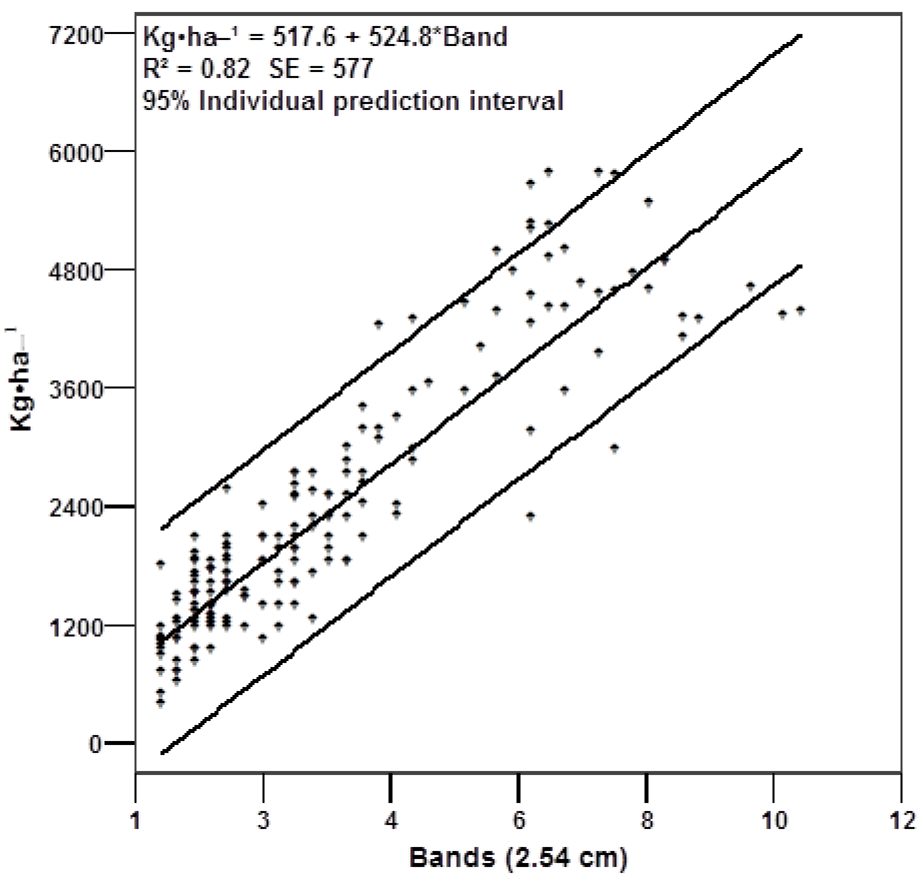

Figure 2. Regression relationship between Visual Obstruction Readings (VOR) bands and standing herbage (kg•ha^{-1}) for clayey ecological sites dominated by cool season grasses with 95% prediction intervals for individual transects in central South Dakota, 1996.

When monitoring was required at the landscape level, sampling efficiency was related to area of land (Benkobi 2000; Fig. 5). A minimum of approximately 16,000 ha (39,539 acres), 62 sections or 248 quarter sections was recommended for a landscape level of sampling. For a 10% sample, 24 quarter sections for obtaining VOR measurements would be adequate. The area to be monitored would need to be stratified to ensure transects are well distributed. The 24-quarter sections (8 transects/stratum) would be randomly selected. Within each quarter section, one randomly selected transect would be sampled. This option would provide a precise overall estimate of the average VOR within the 16,000 ha. Similar monitoring could be applied to situations of no or heavy grazing provided the categories have approximately 16,000 ha each in this example. However, this option would not provide adequate estimates of VOR for a section or few sections. Four transects per section was the alternative monitoring level, but greater effort would be required to attain the same level of precision for a section or a few sections of land.

The models developed in this study for monitoring vegetation have several constraints. Monitoring sites dominated with warm or cool season grasses required staying within the same ecological site type. The plant species typical of those site types may extend and overlap to other soil types. Sampling other ecological site types with different plant species would produce spurious results when predicting standing herbage. Both models were developed based on standing vegetation that had not been subjected to heavy rain, high winds, hail, or early snow. Otherwise, tall maturing vegetation may be lodged and thus result in estimation errors of standing herbage. The modified Robel pole used in this study (2.54-cm bands) was not as precise or accurate as the poles with 1.27-cm bands for monitoring in short vegetation (Uresk and Benzon 2007, Uresk and Juntti 2008, Uresk et al. 2009*a*, 2009*b*, 2010).

Table 3. Validation data for model (Fig. 2) based on nine sites collected in July 2009. Included are visual obstruction readings (Band 2.54 cm) and measured standing herbage (kg/ha dry matter) with 95% prediction intervals.

	Band	Herbage[a]	UCL	LCL
1	8.48	3,778	6,023	3,651
2	4.4	2,361	3,949	1,604
3	2.05	1,178	2,763	416
4	2.09	1,751	2,783	436
5	4.53	2,440	4,015	1,669
6	8.04	3,781	5,798	3,431
7	1.41	889	2,441	92
8	4.98	2,414	4,243	1,896
9*	8.78	3,249	6,176	3,801

[a] Measured Value; LCL = lower confidence limit; UCL = upper confidence limit; * = >3 Standard Deviations (Outlier).

MANAGEMENT IMPLICATIONS

The modified Robel pole calibrated for ecological sites of the Fort Pierre National Grassland provided resource managers with a rapid, cost effective tool for monitoring vegetation and wildlife habitat to desired levels of residual standing herbage. Guidelines to leave an established standard of band 5 for warm and band 4 for cool season grasses would maintain proper structure for plant diversity and standing herbage to maintain healthy grassland systems. Management of vegetation from short through tall structure provided a diversity of residual standing herbage on the grasslands. Four transects based on the overall regression variance would provide sufficient reliability for monitoring standing herbage for key areas of 259 ha (1 section) or less and at a relative precision of within 20% of the mean with 80% confidence. Validation data from the clayey ecological site indicated monitoring VOR and standing herbage throughout the grazing season was feasible. Future recommendations are that a pole with 1.27-cm bands be used for more precise and accurate monitoring and estimation of standing herbage. The current standard (2.54-cm bands) may easily be converted to 1.27-cm bands.

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